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From 1920 to 1937 there is no record that engineering geologists were employed, although there were several mining engineers under engineering titles.

It was not until 1937 that a Mineral Technologist was hired, primarily for research into the reactive aggregate problem, and also for the study of aggregates, with minor attention to cut slope design or foundation investigations. During this time some experimentation was undertaken using the seismic and resistivity methods of exploration.

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THE DEVELOPMENT AND UTILIZATION OF ENGINEERING GEOLOGY IN THE CALIFORNIA DIVISION OF HIGHWAYS

By
E. D. Drew
Associate Engineering Geologist

Presented at the 14th Annual Symposium
on Highway Engineering Geology at
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By

E. D. Drew*

Introduction

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*Associate Engineering Geologist, Materials and Research Department, California Division of Highways, Sacramento, California

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In 1944 Engineering Geologist classes were established in the State Civil Service and personnel were hired in these classes. Programs of training and research were then initiated in the fields of foundation exploration and soil mechanics for the purpose of training geologists in these areas.

On the staff of the Division of Highways today are approximately 25 engineering geologists, three mining engineers and two highway technicians with degrees in geology. Six are employed by the Materials and Research Department and the remainder are assigned in three of the district offices. The Bridge Department, which functions as a separate unit in the exploration for structures, employs 16 geologists divided between the north and south sections of the State.

The value of geology to highway construction is now recognized and the services of geologists are constantly being applied to all fields of engineering geology.

Construction Materials

California, like other states, due to its geography, geomorphic provinces and geographic boundaries of its 11 highway districts, has difficulty in developing suitable construction materials in some areas. Urban development is becoming a factor in locating sources of material within economic haul. This is becoming more noticeable in the metropolitan areas where the construction of high type freeways and structures are contemplated. Therefore, one of the most important functions of the geologic staff is the continuous search for satisfactory construction materials in those areas which are deficient, and the development of new areas where proposed future construction is in the long-range stage.

After a possible source of materials has been located, the geologic factors at the site frequently control its economic usefulness. The extent of the deposit, the amount of overburden, the degree of weathering, the presence of deleterious rocks and minerals must all be known. The geologist can use several methods for exploring the site: (1) geologic mapping; (2) photogeology; (3) geophysics; (4) borings.

The geologist can provide valuable assistance in laying out a program of exploration; sampling and testing a source of material will give results which will be indicative of the quality of material that can be produced.

Geologic mapping is the basic tool used by the geologist. By working in the field, the geologist maps the areal extent of formations and their structures. In recent years photogeology, the technique of plotting geology from aerial photos, has

The "Big Cut"

One of the main highways giving the population of the San Francisco Bay area access to inland areas is U.S. Highway 40 which skirts the northeast shores of San Francisco Bay, crosses over the Carquinez Straits, progresses northerly a few miles and then heads easterly across the State. When the original Carquinez Bridge was completed in 1927 it was one of the nation's outstanding steel bridges, and the highway was very adequate for the traffic of the times. As the years passed, this highway became more and more congested because of insufficient lanes and innumerable bottlenecks in the many small towns through which the road passed. A bold solution to this traffic bottleneck was the construction of a second bridge parallel to the 1927 structure, and the rerouting of the highway across Tormey Valley east of the original highway. The chief obstacle in the way of the new routing was a large hill just south of the Straits. The projected line penetrated this hill to a maximum depth of nearly 350 feet. The natural terrain was standing on slopes approximating 3:1 or flatter, and many slide scarps were visible, indicating surface sloughing. The area was known to contain two active faults: the Franklin Thrust and the Mare Island Fault; and the region is subject to seismic activity. The earthquake record of the region since 1854 shows four shocks with intensities of X on the Rossi-Forel scale and 58 of lesser intensity. Studies were made of the relative cost of tunnel construction vs. open cut. The high cost and uncertainties of future permanence eliminated tunnel construction as a practical alternate. An investigation was then made in a study of construction by open cut methods, and subsequently the construction was made in this manner (See Figs. 1 and 2).

In the fall of 1953 and the spring of 1954 several deep exploratory core holes were made in the proposed cut area. In general the deposits were soft interbedded shales and sandstones of the Cretaceous-Paleocene Age, but the sediments ranged from hard sandstone to soft friable sand, from firm silty shale to soft clay-shale. Substantial evidence of ground water was disclosed by the borings. When deposited, the seidments that form this region were uniform and competent, but intensive folding and faulting has greatly weakened the masses. The locations of borings are shown on the plan of the cut and on the typical cross-section (Fig. 4). All of the borings were bailed to within a few feet of the bottom of the casing, and the rising water level recorded for a period of time after the bailing to obtain an indication of the general permeability of the formations.

The character of the formations as determined by the explorations may be summarized by the following excerpts from the report of this foundation investigation:

> "In summary, it is believed that it is feasible to construct the proposed road...without serious risks. It should be recognized that the cuts would be high and the soil far from ideal. Even with proper slope design, some surface sloughing and minor slides can probably be expected. The possibilities of a major slide, one that would close all or even two or three lanes of the road,

are very remote. It is believed that the risks involved ...are not seriously greater than they are on numerous major roads where foundation design problems are complex."

To aid in visualizing the variations in conditions within this cut a scale geological model was constructed, and the deduced and actual geological conditions were shown on various surfaces of the model. A photograph of this model is reproduced in Fig. 3.

On the basis of all available information about the soils and geological conditions in the area, it was determined that this road could be designed as an open cut through the hill south of the Straits. The typical cross-section reproduced in Fig. 4 shows approximately the maximum section through the cut. The cut was designed with slopes of 2:1 and 30-foot wide benches at 60-foot vertical intervals. This cut was widened about 30 feet on each side at roadway grade to provide protection against the blocking of traffic lanes in the event large slides should take place after the road was opened to traffic. A substantial number of horizontal drains were to be installed at various levels in the cut.

As designed, the "Big Cut" had a length of about 3000 feet, a top width at the crest of 1370 feet and a maximum depth of 350 feet. The total volume was calculated to be more than 9,000,000 cubic yards.

Excavation of the "Big Cut" was started in late March, 1956, and completed in June, 1958. As the excavation was deepened, ground water levels were recorded in numerous wells and horizontal drains were drilled into areas where the water level did not drop rapidly with the deepening of the cut. On the whole, the designed and constructed slopes have been stable. From time to time small slides have occurred at various points on the faces of the cuts. One slide of rather major proportions took place at the north end of the cut in an area known locally as Valona. The extent of this slide in relation to the magnitude of the cut may be seen in the photographs reproduced in Figs. 1 and 2.

In February, 1958, some cracking was observed above the cut in the area on the west side of the cut, noted above. Subsequently, a retaining wall was badly cracked and noticeable cracks showed up in the basements of two of the houses at the top of the slope. The condition grew progressively worse, and several houses had to be removed and the slide mass removed. After this treatment this area showed no further evidence of instability.

In relation to the total volume of this cut, the slide was of rather nominal size. Nevertheless, approximately 125,000 cubic yards of earth were removed in correcting this slide. Had this cut been designed initially on a slope sufficiently flat to guarantee 100% security against slides, a rather enormous additional quantity of roadway excavation would have been required (several million cubic yards).

This large cut is another example of a highway project in which soils and geological explorations and test borings provided very essential design information. The knowledge (information from the borings) furnished to prospective contractors, placed all bidders on a relatively even basis in judging the rippability of the formations and in estimating the costs involved in handling the excavation materials. Knowledge of the character of the formations and ground water conditions were extremely valuable in designing this cut.

On the whole, this excavation has been exceedingly successful. It is a tribute to the combined experience and judgment of the engineers and geologists who developed and executed its design.

increased in use and has saved many hours of arduous field work.

Geophysical methods are profitably applied in certain instances. Seismic surveys, using the principle of refracted waves, can determine depth of overburden or weathering, or when applicable can be used to quickly extend information from a boring. Quarry sites can be delineated in areas not accessible to equipment. Resistivity surveys, using the principle of electrical resistance of materials, can sometimes be used to detect changes in lithology of sedimentary material. It, too, under favorable conditions, can rapidly extend the area of validity of borings.

In the laboratory, additional information can be obtained by various methods. For instance, a petrographic study will determine the percent of reactive material in an aggregate and, in the studies of riprap and quarry rock to be crushed for aggregates, thin sections are prepared and a complete petrographic analysis is made.

<u>Cut Slope Design</u>

The first step in a cut slope design is to get the broad picture. This involves soils and geological examinations of surface conditions, searches for evidences of stability or instability, and studies of the performance of any existing natural slopes and cuts in the area. It also includes a look at features that can change the stability of a slope, such as natural changes in ground water conditions, earthquakes, etc., and man-made changes such as aggravated ground water caused by infiltration from adjacent lawns, broken water mains, leaky sewer lines, etc.

The information needed for the economical design of cut slopes includes the nature and strengths of the materials that will be excavated, ground water conditions, the attitude in beds of sedimentary rocks, the degree of weathering, the extent of joints, bedding planes, fractures, and other surfaces of potential weakness, and the presence of landslides, active or ancient. To obtain this information several of the following methods commonly are utilized: visual inspection on the ground, study of topographic maps and airphotos, model construction, geological surveys, geophysical explorations, explorations by borings, either vertical or horizontal, evaluation of boring data, ground water observations, and testing of undisturbed soil samples or rock cores.

In the California Division of Highways an effort is made to avoid cut slope failures, but it would be necessary to be very conservative to avoid all failures. When any of importance occur they are studied very carefully to try to determine the causes. Sometimes the causes are obvious; other times they are very obscure.

The stability of cut slopes usually can be improved by one or more of the following methods:

1. Changing highway alignment or grade.
2. Flattening slope or unloading upper part of cut slope.
3. Adding support at the toe in the form of buttresses.
4. Drainage.

Obviously, for reasons of economy, cut slopes should be as steep as possible, consistent with stability. Typical slopes for various materials might be somewhat as follows: in cohesionless sands the slope should be no steeper than 1½:1, since this is about the angle of repose for such soil; in cohesive soils, containing silt and clay along with sand, slopes of 1½:1 or flatter are usually in order; in cemented sediments, such as sandstone, shale, and conglomerate, steeper slopes may be used, depending on the degree of cementation, bedding, jointing and ground water conditions; in weathered rock, slopes may vary from 3/4:1 to 2:1, again depending on degree of weathering, ground water, etc.; and in hard fresh rock slopes as steep as ½:1 or 3/4:1 are sometimes possible.

After all the factors and information has been obtained an evaluation is made by the different sections and a slope design based on the analysis of the data and opinions is made for submittal to the Headquarters and District Design Departments.

Landslides

Diversity of formations, complex fault systems, and variable climatic conditions accentuate the problem of landslides in California. Almost every classification of slide can be found, and it is impossible to set up a standard method of correction for the many types of slides found in the State.

Preliminary geologic studies of proposed routes have been valuable in avoiding areas of unstability. When these areas cannot be avoided, a comprehensive study and investigation is made to determine what methods must be used to furnish the greatest stability to the roadway. Horizontal drains, stabilization trenches, stripping and struts are a few of the methods most frequently employed.

Approximately 70 percent of the slides occur in the Northern Coast Range Province, although a few of the more spectacular and complex of treatment have occurred in the seemingly stable Sierra Nevadas.

Geophysical Exploration

In 1935, the late E. R. Shepard, Research Engineer with the Bureau of Public Roads, demonstrated the use of the resistivity and seismic methods in highway exploration to personnel in the Division. Using plans furnished by the Bureau, the Materials and Research Department assembled seismic and resistivity equipment. This equipment was crude when compared to present-day instrumentation but the principle and interpretation were the same. The equipment did not receive wide-spread use and the lack of trained personnel in the interpretation of the records left much to be desired when a knowledge of the geologic conditions is essential.

In 1947 the Department purchased a 12-channel Century Seismograph, a Michimho Vibroground, and a Bureau of Public Roads resistivity instrument. This equipment has had fairly continuous use in all sections of the State and is generally used to extend information from boreholes and to obtain subsurface data in areas not accessible to drilling equipment. It is used in the exploration of aggregate sites, quarries, cut slopes, fill foundations and in rippability studies.

In 1962 the Department purchased one of the hammer type seismographs, and a 12-channel ER-75 Porta-Seis Interval Timer. This new equipment has decreased field time and reduced personnel, resulting in a considerable saving in job costs.

In formations where good correlation with existing exposures or correlation with other data such as borings can be obtained, the seismic method of exploration is a valuable tool. It develops information along a continuous profile, whereas boring data is valid only at a specific location. Therefore, when the seismic method of exploration can be used in combination with other means of investigation the data thus obtained may be relatively economical.

Normally a three-man crew is required which will be able to make eight to twelve seismic tests per day at a cost of $100 to $150 per day.

In addition to the necessity for correlation with observed or known conditions, some other deficiencies are: poor results in areas of high organic content such as peat, the difficulties of using explosives in populated areas, and questionable results due to the heterogeneous nature of the formations being explored.

In the earth resistivity method of investigation, a crew of 2 to 4 men is used. This operation costs from $100 to $200 per day. Such a crew can make 15 to 20 tests per day. The data can often be interpreted in the field. Thus, the information obtained is frequently less expensive than that obtained by seismic studies or other means of investigation. It is almost always necessary to supplement such data with other types of exploration.

It should be kept in mind that optimum conditions are necessary in order to obtain satisfactory results from the earth resistivity method of exploration. These conditions are: appreciable differences in resistivity of soils involved, stratification parallel to the ground surface, and sufficient area of uniform soil profile in the zone to eliminate side effects.

Some conditions that may cause difficulties are: stray currents leaving cross-country pipe lines or emanating from electric railway systems in urban areas, or buried utilities such as water and gas pipes.

Conservative interpretation, geologic knowledge and the use of borings have proven the value of geophysics as an aid to highway construction in California.

Photogeology

The use of photogeology is rapidly becoming one of the most important working tools of the geologist, saving many weeks of field work. Proper interpretation of air photos can, if correctly applied, save thousands of dollars in all phases of highway construction.

Photogeology, borings and geophysics in the order named, will be the means more frequently used to keep pace with the expanding highway program and the increased demand for greater quantities of construction materials.

Special Investigations

Another field in which geologists are frequently called upon is to furnish testimony and evidence as expert witnesses in condemnation and damage suits brought against the Division.

In one instance geology, geophysics, photogeology and cores were all used as evidence which resulted in a verdict favorable to the State and an estimated saving of over $250,000.00. At the present time there are two court cases pending in which Division geologists are being used as expert witnesses.

Secondary Alteration

Considerable research is being made in the area of secondary mineral alteration of construction materials. It has been found that certain rocks, principally the volcanics, are subject to breakdown and progressive failure after being used in the roadway, stockpiled, or placed on slopes. Thin sections, and petrographic analysis, followed by further physical tests and field studies are a few of the methods being used to detect alteration before the rock is accepted or rejected for use.

Not all volcanics are suspect, and to date it has been found that certain granites, ultra-basics and sandstones are susceptible to secondary alteration or breakdown. As the locating, production and use of all types of construction materials are major items of highway development, continuous research is being carried on, and it is hoped that in the near future sufficient data will be obtained for publication.

Clay Mineralogy

During 1962 Differential Thermal Analysis has been extremely useful in the identification of clay minerals and good correlation has been obtained between the expansion pressure tests and the D.T.A. It is also used in the investigation of the clays from slip surfaces of landslides, gouge from fault zones and clay and soil cores from borings. The recognition of the presence of montmorillonite clays in base and subbase materials can readily be determined by the D.T.A. and has resulted in a closer control on suspect or borderline material.

Recently, X-ray diffraction equipment has been purchased and it is planned to continue research of the clay minerals in relation to construction materials using both D.T.A. and X-ray methods.

Conclusion

The engineering geologist should be ready at all times to furnish to the engineer any information he has or can obtain. In this manner the engineer can proceed in the preliminary stage to plan ahead on projects that might be delayed pending a formal report. A mutual understanding between the geologist and engineer is essential and this can only be obtained by recognizing each others problems.

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REFERENCES

T. W. Smith and H. R. Cedergren, "Cut Slope Design and Some Case Histories," Fourth Pacific Area National Meeting of the American Society for Testing and Materials, October 1962, Los Angeles, California.

A CASE HISTORY

the

"BIG CUT"

Fig. 1 - Aerial View of Completed Carquinez Cut and Southern Approach to Twin Bridges

Fig. 2 - Aerial View Showing Magnitude of Carquinez Cut

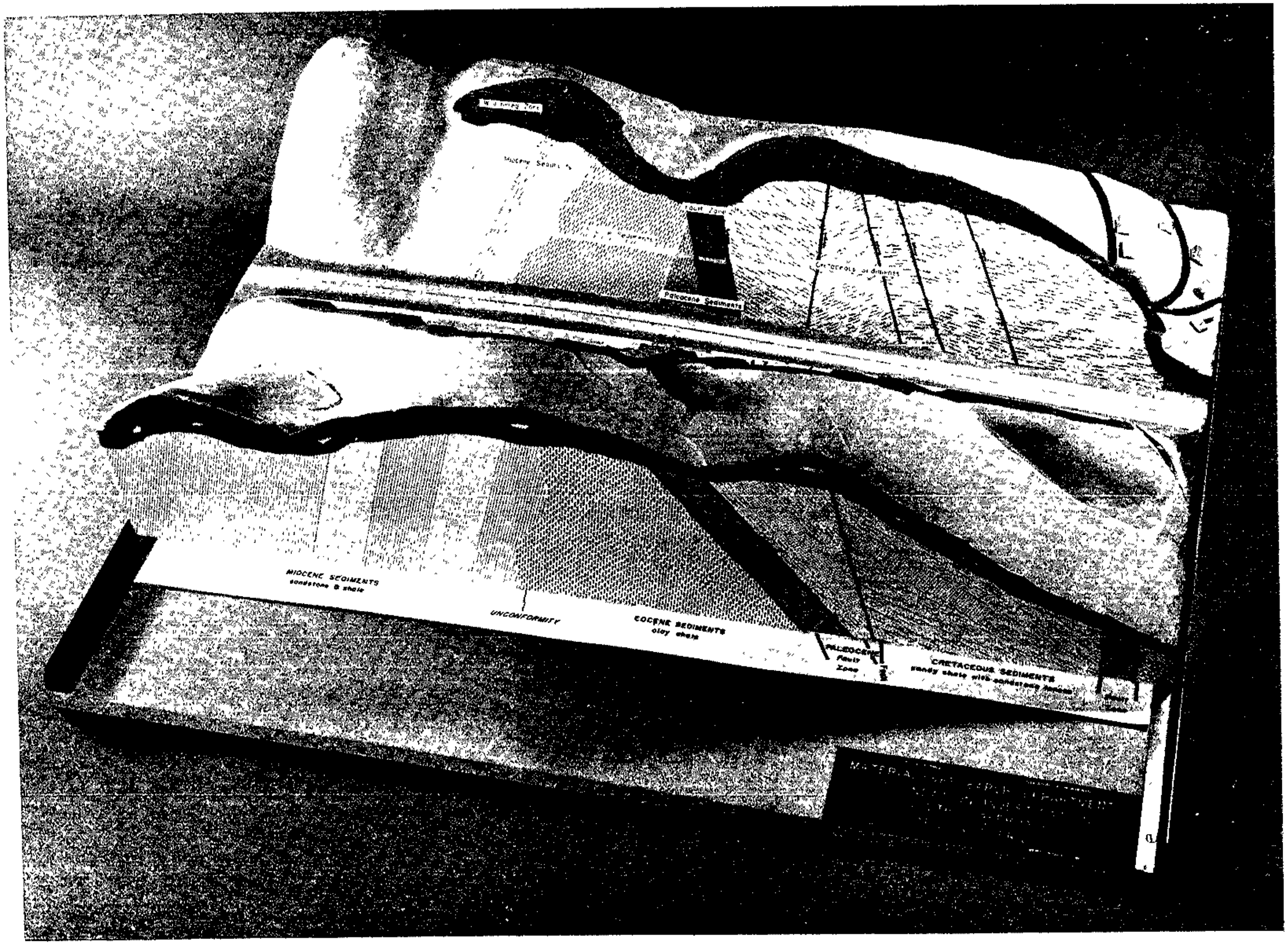

Fig. 3 - View of Model Showing Preliminary (Front Profile) and Actual (Rear Profile) Geology of Carquinez Cut

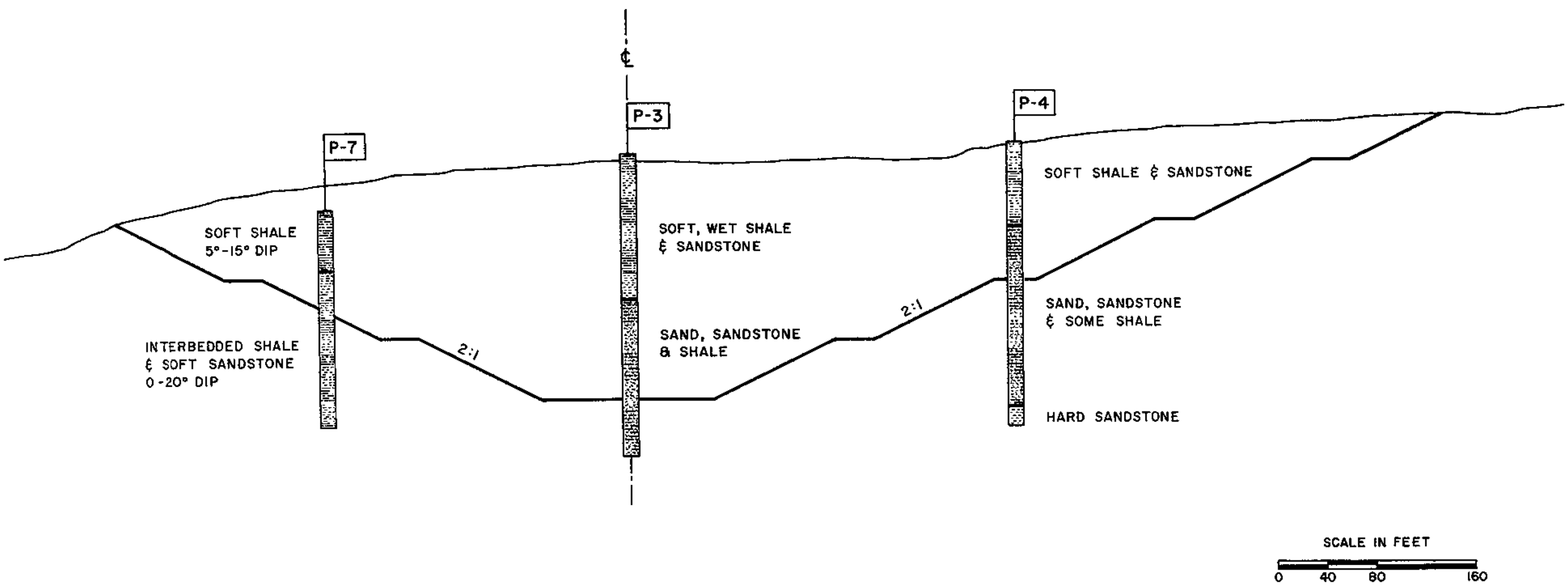

FIG. 4 TYPICAL SECTION OF CARQUINEZ CUT WITH SIMPLIFIED BORINGS